RADCOM TECHNICAL FEATURE

RF Coil Dimensions - The Easy Way

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THIS ARTICLE REMOVES much of the mystery from the design of single-layer radio-frequency coils, by providing simplified yet acceptably accurate formulas for those who usually find calculations daunting. Pre-calculated tables are included for those who prefer to avoid calculations altogether or to check the results of calculations. Worked examples in a no-frills manner are included for guidance on using the formulas.

If making an RF Coil from existing formulas winds you up, try the methods described here.

RESONANCE

HF RADIO AND RF COILS are inseparable. Without the RF coil there is no LC resonance, and without resonance there is no radio. This is true even of the satellite microwave bands where microstrip and dielectric resonators prevail, and yet reception of their direct TV broadcasts requires an immediate down-conversion in frequency to the more familiar VHF and HF ranges, ie to the domain of the RF coil/capacitor (LC) resonator.

Before discussing RF coils however, consider first the familiar formula for calculation of the resonant frequency of a series LC tuned circuit, that is, an RF coil with a capacitor connected in series with it.

Assuming good quality LC components with minimal resistive losses, this formula is equally valid for a parallel resonant LC circuit, ie a coil with a capacitor connected across it.

$$\text{Frequency } f = \frac{1}{2\pi\sqrt{L \times C}}$$

It seems harmless enough at first glance, but in amateur radio applications it is far from being user friendly, in that it needs the values for inductance L to be in henries (H), and capacitance (C) to be in farads (F). Then it would give the frequency in hertz (Hz) not the more relevant megahertz (MHz).

The frequency range of interest to the typical short-wave radio enthusiast is, say, from about 2 - 200MHz. Not far below 2MHz lies the medium-wave broadcast band which requires multi-layer RF coils, and above 200MHz the coil dimensions become small enough to be replaced by other resonance techniques such as microstrip transmission lines.

Inductance values of RF coils at the frequencies mentioned, range from about 50µH at 2MHz, down to about 0.1µH at 200MHz - ie *millionths* of a henry, not henries.

And similarly for the values of capacitors associated with those small values of inductance, ranging from around 200 picofarad (pF) at 2MHz, to a few pF at 200MHz - again not farads, but *million-millionths* of a farad.

Arithmetical handling of such miniscule dimensions can present a problem for the non-mathematically inclined. Certainly, even some scientific pocket-calculators cannot accept decimal fraction calculations in the form 0.000005 (for 5µH) multiplied by 0.00000000005 (for 50pF) to give a value for L x C as required in the formula for resonant frequency.

The alternative methods using logarithms or powers of ten with or without a calculator, may be equally unpalatable to the radio experimenter.

So, with the ordinary pocket-calculator and its user in mind, the formula for frequency of a series or parallel LC circuit resonant in the HF/VHF range, has been simplified to:

$$\text{Frequency } f \text{ (in MHz)} = \frac{159}{\sqrt{L \times C}}$$

Where L is inductance in µH
and C is capacitance in pF

Example No 1

Find the resonant frequency of an LC tuned-circuit comprising a coil of inductance L = 2µH in parallel or series with a capacitor C = 50pF.

f (MHz) = (159) divided by square root of (2 x 50)
= (159) divided by (10)
= 15.9MHz

Most of the basic pocket-calculators can give the square root of a number as well as add, subtract, multiply and divide. Some may even have an invert (1/x) key which is useful for working out fractions, because it allows the denominator (below the line) to be calculated first, then inverted, then multiplied by the numerator (above the line).

To demonstrate this, the previous example would be calculated by pressing key entries as follows:-

Example No 2

2 [x] 50 [=] 100
[√] [=] 10
[1/x] [=] 0.1
[x] 159 [=] *15.9* (MHz)

INDUCTANCE BY CALCULATION

A LONG-ESTABLISHED FORMULA for the calculation of the inductance of a coil of known dimensions is:-

$$L\mu H = \frac{(RN)^2}{(9R + 10S)}$$

where R is the mean radius in inches.

Converting to metric units and *simplifying* gives the G3BIK formula for inductance:-

$$L\mu H = \frac{(DN)^2}{500(D + 2S)}$$

where D = inner diameter of coil (mm)
N = Number of turns
S = span (length) of winding (mm). Assumes S equal to or greater than approx D/2

This simplified formula gives results which are accurate enough for practical purposes, typically to within 2% of the earlier established formula. See **Fig 1** for definition of coil dimensions.

It does *not* require information on the wire with which the coil is wound. One needs only to measure in millimetres the inside diameter D of the coil (or the outside diameter of the former on which it is wound), the distance S in millimetres from end to end of the winding, and to count the number of turns by running a soft-pointed probe over them.

The calculation is quick and easy using a basic pocket-calculator first to calculate below the line, invert that value, then multiply above the line, using key entries as follows:

2 [x] S PRESS [=]
[+] D PRESS [=]
[x] 500 PRESS [=]
PRESS [1/x]
[x] D [x] D [x] N [x] N
PRESS [=]

Alternatively, if the calculator does not have the inverting [1/x] key, the memory key may be used thus:-

2 [x] S PRESS [=]
[+] D PRESS [=]

[X] 500 PRESS [=]

PRESS [M+]

PRESS [C]

D [X] D [X] N [X] N [÷] [MR]

PRESS [=]

For practice and to gain confidence, the above key entry sequence should be used in the following examples:-

Example No 3

Calculate the inductance of an enamelled copper-wire coil of:-
inner diameter D = 12.5mm
no of turns N = 41
span of winding S = 21mm

$$L\mu H = \frac{(DN)^2}{500(D+2S)} = \frac{12.5\times12.5\times41\times41}{500\times(12.5+(2\times21))}$$

= 10μH approx

Example No 4

Calculate the inductance of an enamelled copper-wire coil of:-
inner diameter D = 4.8mm
no of turns N = 14
span of winding S = 7mm

$$L\mu H = \frac{(DN)^2}{500(D+2S)} = \frac{4.8\times4.8\times14\times14}{500\times(4.8+(2\times7))}$$

= 0.5μH

All results have been rounded up or down to the nearest whole digit.

NUMBER OF TURNS BY CALCULATION

THE CONVERSE OF FINDING the inductance of a given number of turns, is to determine the number of turns required to produce a required value of inductance, from given coil diameter and wire details.

Classical published formulas for the calculation of the number of turns for an RF coil, can be horrific and daunting. Take for example the following formula prior to simplification:-

$$N = \frac{5L}{nR^2}\left(1+\sqrt{1+\frac{0.36n^2R^3}{L}}\right)$$

Again a not too user friendly formula, being in dimensions of yesteryear and involving the radius rather than the more measurable diameter.

Converting to metric, and to inner diameter instead of outer radius, and simplifying, gives the G3BIK formula for number of turns of an air-cored single layer coil:-

$$N = \frac{500L}{nD^2}\left(1+\sqrt{1+\frac{(n^2D^3)}{(500L)}}\right)$$

where N = number of turns, air-cored
L = inductance in μH
n = turns per mm (close-wound or spaced)
D = inner diameter in mm

It may still look somewhat complex, but is in fact *really* easy to use, as will now be demonstrated by worked examples and guidance on how to manipulate the everyday non-scientific type of pocket-calculator.

For this formula, one needs to know the turns per millimetre, ie the winding-pitch for the coil. Assuming close-wound coils, the turns per mm values are as given in Table 1 for the most practical range of standard wire gauge enamelled copper-wires.

Note that turns per mm does not simply equal (1/dia), because it allows for the thickness of the enamel covering. The diameter of the wire is not in fact needed, and is given for interest only.

If there is any doubt about the actual gauge of the wire available, the turns per millimetre can be easily obtained by close-winding enough turns onto the coil-former or pencil to cover 10mm, then to divide by ten to get turns per mm for a close-wound coil.

The simplified formula for number of turns N may be calculated on a pocket-calculator by the following key entries:-

n [X] n [X] D [X] D [X] D

[÷] 500 [÷] L PRESS [=]

[+] 1 PRESS [=]

PRESS [√]

[+] 1 PRESS [=]

[X] 500 [X] L [÷] n [÷] D

[÷] D [=] Number of turns N

Example No 5

Inductance of L = 0.5μH to be close-wound on standard former of 4.8mm dia, with air core, using28SWG enamelled copper-wire, close-wound.

From **Table 1**, number of turns per mm for 28SWG wire = 2.4 t/mm = n

For formula calculations, L = 0.5
D = 4.8
n = 2.4

Using calculator, number of turns is given by:-

2.4 [X] 2.4 [X] 4.8 [X] 4.8

[X] 4.8 [÷] 500 [÷] 0.5

PRESS [=] *2.55*

[+] 1 PRESS [=] *3.55*

PRESS [√] *1.88*

[+] 1 PRESS [=] *2.88*

[X] 500 [X] 0.5 [÷] 2.4 [÷]

4.8 [÷] 4.8 [=] *13* turns of 28SWG wire on 4.8mm dia former

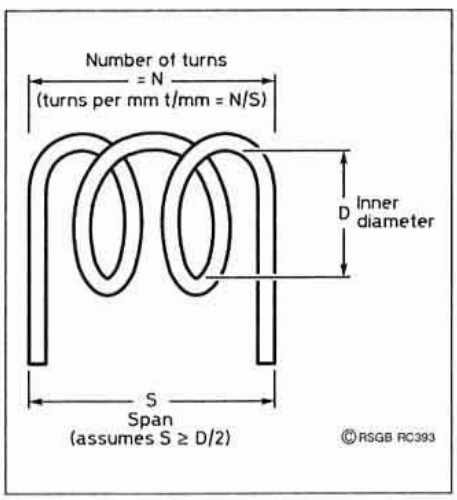

Fig 1: Coil Dimensions: D = Inner Diameter mm; N = Number of Turns; S = Span of Winding mm.

Example No 6

L required = 10μH
Dia D = 12.5mm
Wire = 26SWG enamelled
From Table 1 n = 1.98 t/mm close-wound

Using calculator, number of turns is given by:-

1.98 [X] 1.98 [X] 12.5 [X] 12.5

[X] 12.5 [÷] 500 [÷] 10

PRESS [=] *1.53*

[+] 1 PRESS [=] *2.53*

PRESS [√] *1.59*

[+] 1 PRESS [=] *2.59*

[X] 500 [X] 10 [÷] 1.98 [÷]

12.5 [÷] 12.5 [=] *42* turns of 26SWG wire on 12.5mm former

USING THE TABLES

THE PRECEDING EXAMPLES were based on the simplified formulas for inductance and formula for number of turns as appropriate.

To avoid calculations however, **Tables 2 to 6** provide a quick and easy way of determining either inductance or number of turns, over the range of values of immediate interest, and assuming close-wound coils. The results are again based upon the simplified formulas and are exact enough for practical purposes.

The table entries indicated with a # were calculated from the longer established empirical formulas by others, and are included to demonstrate the comparative accuracy of the G3BIK simplified formulas.

The calculated values given in the tables have been rounded off for convenience of tabulation.

Use of the tables is straightforward, to derive the coil dimensions for a required value of inductance; or conversely the inductance value from dimensions of an existing coil.

To determine number of turns and span in millimetres for a required value of inductance L in μH:-

1 Decide diameter of coil former and select related Table
2 Decide wire gauge to be used and go to related column heading
3 Move down column to intersect with required L μH

4 Read off number of turns N, and Coil-Span S mm

To determine value of L µH for an existing coil:-

1 Measure inner diameter of coil D mm
2 Select related Table
3 Count number of turns N
4 Measure coil-span S mm
5 Divide N by S to get turns per mm (t/mm = n = N divided by S)
6 Find that t/mm column heading
7 Look down its N column to find the nearest number of turns
8 Read off inductance L µH

Whilst the tables apply to close-wound single layer coils, the previous G3BIK simplified formulas for inductance and number of turns do also apply to coils which are wound with spaced turns, ie the turns per millimetre value will be less than that for close-wound.

It will be appreciated that it is almost impossible to hand-wind a coil to perfection, because of unintentional gaps in spacing between turns and the fact that the connecting-tails add to the inductance — as do the connections from a resonating capacitor.

In all of the previous considerations allowance has been made for connecting-tails of circa 10mm length, but on coils of inductance less than say 0.2µH (for use at VHF) the coil tails will significantly affect the inductance value, so they must be kept as short as possible.

Fractional values for the number of turns obtained from the tables should *not* be taken as sacrosanct, but should in practice be rounded up or down to the nearest whole number. This also applies to the coil span dimensions.

It should be noted also that the accuracy of calculated inductance diminishes when the coil span becomes significantly greater than, say, three times the coil diameter.

COIL CORES

AS PREVIOUSLY DISCUSSED, the formulas and related Tables assume an air-core within the coil. The standard 4.8mm and 7.1mm formers do have a threaded inner-surface to allow the use of a 4mm or 6mm diameter screw-slug respectively for adjustment of the inductance value.

Generalising, an iron-dust or ferrite slug *increases* the inductance as the slug is screwed into the coil, whilst conversely, a non-ferrous (eg brass or aluminium) slug decreases the inductance.

There are different grades of iron-dust or ferrite slug material, some of which are more suited for use at VHF or HF than others - but that is a subject in its own right and will not be expanded upon herein. Without being definitive, suffice to say that some iron-dust slugs can almost quadruple the inductance value, whereas a non-ferrous slug would typically produce only a modest decrease in inductance to say half of its former value.

Some minor adjustment of inductance *can* be achieved by opening out the spacing between turns, the inductance decreasing as the spacing increases.

It should be borne in mind that increasing the value of inductance in an LC resonant circuit lowers the resonant frequency, whilst decreasing the value of inductance increases the resonant frequency.

The previous calculations and tables apply reasonably well to non-enamelled wire, on the assumption that the close-spaced turns do not electrically touch.

SWG	30	28	26	24	22	20	18	16
dia mm	0.31	0.38	0.46	0.56	0.71	0.91	1.22	1.63
t/mm	2.85	2.40	1.98	1.64	1.30	1.02	0.78	0.58

Table 1: Enamelled Copper Wire Dimensions.

WINDING COILS

THE COIL DIAMETERS in the Tables cater for the use of standard coil-formers or readily available tubular materials such as plastic water-pipe or electrical conduit.

On the larger diameter formers, two small close-spaced holes drilled at each end of the coil-span would allow the wire ends to be secured by being fed into the former via one hole and out again via the adjacent hole. Alternatively, a solder tag secured by a small diameter machine-screw and nut may be used to anchor the wire at each end of the former.

Inner Diameter D = 25mm	N = Number of Turns										S = Span of Winding mm			
SWG	30		28		26		24		22		20		18	
t/mm	2.85		2.40		1.98		1.64		1.30		1.02		0.78	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S
LµH														
0.5#	3.17	1.1	3.20	1.3	3.33	1.6	3.3	2.0	3.4	2.6	3.5	3.4	3.6	4.6
0.5	3.31	1.2	3.33	1.4	3.37	1.7	3.4	2.1	3.5	2.7	3.6	3.5	3.7	4.8
1.0	4.8	1.7	4.8	2.0	4.9	2.5	5.0	3.0	5.1	4.0	5.3	5.2	5.6	7.2
2.0	6.9	2.4	7.0	2.9	7.2	3.6	7.4	4.5	7.7	5.9	8.1	7.9	8.7	11
3.0	8.6	3.3	8.80	3.7	9.1	4.6	9.4	5.7	9.8	7.6	10.5	10	11.4	15
4.0	10.1	3.6	10.4	4.3	10.7	5.4	11.1	6.8	11.7	9.0	12.6	12	13.9	18
5.0#	11.1	3.9	11.4	4.8	11.8	6.0	12.4	7.5	13.2	10	14.3	14	16.1	21#
5.0	11.5	4.0	11.8	4.9	12.2	6.2	12.7	7.8	13.5	10	14.7	14	16.4	21
6.0	12.8	4.5	13.1	5.5	13.6	6.9	14.3	8.7	15.3	12	16.7	16	18.7	24
7.0	14.0	4.9	14.4	6.0	15.0	7.6	15.7	9.6	16.9	13	18.5	18	21.0	27
8.0	15.1	5.3	15.6	6.5	16.3	8.2	17.1	11	18.5	14	20.4	20	23.3	30
9.0	16.2	5.7	16.8	7.0	17.5	8.9	18.5	11	20.1	15	22.2	22	25.5	33
10.0#	16.7	5.9	17.3	7.2	18.2	9.2	19.4	12	21.2	16	23.7	23	27.5	35#
10.0	17.2	6.0	17.9	7.4	18.8	9.5	19.8	12	21.8	17	24.0	24	27.2	36
20.0	26.4	9.3	27.7	12	29.7	15	32.0	20	35.8	28	41.1	40	49.2	63
30.0	34.3	12	35.5	15	39.5	20	43.2	26	49.1	38	57.5	56	70.1	90
40.0	41.7	15	44.6	19	48.7	25	53.9	33	62.1	48	73.6	72	90.0	117
50.0	48.6	17	52.4	22	57.8	29	64.3	39	74.9	58	89.6	88	112	143
50.0#	47.7	17	51.6	22	57.1	29	63.9	39	74.8	58	89.9	88	111	143

= results of non-simplified formulas

Table 2: Inductance of 25mm coil v number of turns v Standard Wire Gauge for close-wound single-layer air-cored coil, of enamelled copper-wire (based on G3BIK simplified formula).

Inner Diameter D = 20mm	N = Number of Turns										S = Span of Winding mm			
SWG	30		28		26		24		22		20		18	
t/mm	2.85		2.40		1.98		1.64		1.30		1.02		0.78	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S
LµH														
0.5	3.76	1.3	3.8	1.6	3.87	2.0	3.94	2.4	4.1	3.1	4.2	4.1	4.4	5.7
1.0	5.5	1.9	5.6	2.3	5.7	2.9	5.8	3.6	6.1	4.7	6.4	6.2	6.9	8.8
2.0	8.0	2.8	8.2	3.4	8.5	4.3	8.8	5.3	9.3	7.1	9.9	9.7	11.0	14
3.0	10.0	3.5	10.4	4	10.8	5	11.2	7	12.0	9	13.1	13	14.7	19
4.0	11.9	4	12.3	5	12.8	6.5	13.5	8	14.6	11	16.0	16	18.3	24
5.0#	13.2	4.6	13.7	5.7	14.4	7.3	15.2	9.3	16.6	12.8	18.6	18.2	21.6	28#
5.0	13.6	4.8	14.1	5.9	14.8	7.5	15.6	9.5	17.0	13.1	18.9	18.5	21.8	28
6.0	15.2	5	15.8	7	16.6	8	12.7	11	19.3	15	21.6	21	25.2	32
7.0	16.7	6	17.4	7	18.4	9	19.6	12	21.6	17	24.4	24	28.6	37
8.0	18.1	6	18.9	8	20.1	10	21.5	13	23.8	18	27.0	27	31.9	40
9.0	19.5	7	20.4	8	21.7	11	23.4	14	26.0	20	29.7	29	35.2	45
10	20.8	7	21.9	9	23.4	12	25.2	15	28.1	22	32.3	32	38.5	49
20	32.8	12	35.1	15	38.3	19	42.3	26	48.7	38	57.7	57	71.1	91
30.0	43.5	15	47.2	20	52.2	26	58.5	36	68.6	53	82.6	81	103	133
40.0	53.7	19	58.7	25	65.7	33	74.4	45	88.3	68	107	105	136	174
50.0	63.5	22	70.0	29	79.0	40	90.1	55	108	83	132	129	168	215

= results from non-simplified formulas

Table 3: Inductance of 20mm coil v number of turns v Standard Wire Gauge for close-wound single-layer air-cored coil, of enamelled copper-wire (based on G3BIK simplified formula).

Inner Diameter D = 12.5mm	N = Number of Turns													
SWG	30		28		26		24		22		20		18	
t/mm	2.85		2.40		1.98		1.64		1.30		1.02		0.78	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S
LμH														
0.5	5.1	1.8	5.2	2.2	5.4	2.7	5.6	3.4	5.9	4.5	6.3	6.2	7.0	8.9
1.0	7.6	2.8	7.8	3.3	8.1	4.1	8.6	5.2	9.3	7.1	10.2	10	11.6	15
2.0	11.5	4.0	12.0	5.0	12.7	6.4	13.7	8.3	15.1	12	17.2	17	20.3	26
3.0	14.8	5	15.7	7	16.8	9	18.3	11	20.6	16	23.9	22	28.8	37
4.0	17.9	6	19.1	8	20.7	10	22.7	14	25.9	20	30.3	30	37.1	48
5.0	20.8	7	22.3	9	24.4	12	26.9	17	31.0	24	36.8	36	45.4	58
6.0	23.6	8	25.4	11	28.0	14	31.2	19	36.2	28	43.2	42	53.7	69
7.0	26.4	9	28.5	12	31.5	16	35.3	22	41.3	32	49.6	49	62.0	79
8.0	29.0	10	31.5	13	35.0	18	39.4	24	46.3	36	55.9	55	70.2	90
9.0	31.6	11	34.5	14	38.5	19	43.4	27	51.3	40	62.3	61	78.4	101
10.0#	33.7	12	37.0	15	41.6	21	47.4	29	56.5	44	69.1	68	87.5	112
10.0	34.2	12	37.4	16	41.9	21	47.5	29	56.3	43	68.6	67	86.7	111
20.0	58.6	21	65.5	27	75.3	38	87.2	53	106	82	132	129	169	217
30.0	82	29	93	39	108	55	127	77	155	120	194	191	251	322
40.0	105	37	120	50	141	71	166	101	205	158	257	252	333	427
50.0	128	45	147	61	173	88	205	125	254	195	320	314	415	532

= results from non-simplified formulas

Table 4: Inductance of 12.5mm coil v number of turns v Standard Wire Gauge for close-wound single-layer air-cored coil, of enamelled copper-wire (based on G3BIK simplified formula).

Inner Diameter D = 7.1mm	N - Number of Turns								S = Span of Winding mm (max 25.4mm)					
SWG	30		28		26		24		22		20		18	
t/mm	2.85		2.40		1.98		1.64		1.30		1.02		0.78	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S
LμH														
0.5 #	*7.7*	*2.7*	*8.2*	*3.4*	*8.8*	*4.4*	*9.5*	*5.8*	*10.8*	*8.3*	*12.5*	*12.2*	*15.1*	*19#*
0.5	7.9	2.8	8.4	3.5	9.0	4.5	9.7	5.9	10.9	8.4	12.5	12.3	15.1	19
1.0	12.6	4.4	13.5	5.6	14.8	7.5	16.4	10	19.0	15	22.6	22.0	28.0	36
2.0	20.7	7.3	22.7	9.5	25.6	12.9	29.0	17.7	34.6	26.6				
3.0	28.3	9.9	31.5	13.1	35.9	18.2	41.4	25.2	50.0	38.5				
4.0	35.7	12.5	40.1	16.7	46.2	23.3	53.6	32.7						
5.0 #	42.9	15.0	48.6	20.3	56.6	28.6 #								
5.0	43.0	15.1	48.6	20.2	56.3	28.5								
6.0	50.2	17.6	57.0	23.8	66.5	33.6								
7.0	57.3	20.1	65.4	27.3										
8.0	68.8	24.1	73.8	30.7										
9.0	71.5	25.1	82.1	34.2										
10.0	71.5	25.1	82.1	34.2										
10.0	78.6	27.6												

= results from non-simplified formulas

Table 5: Inductance of 7.1mm coil v number of turns v Standard Wire Gauge for close-wound single-layer air-cored coil, of enamelled copper-wire (based on G3BIK simplified formula).

Inner Diameter D = 4.8mm	N = Number of Turns								S = Span of Winding mm (max 15mm)					
SWG	30		28		26		24		22		20		18	
t/mm	2.85		2.40		1.98		1.64		1.30		1.02		0.78	
	N	S	N	S	N	S	N	S	N	S	N	S	N	S
LμH														
0.5	12.0	4.2	13.0	5.4	14.5	7.3	16.4	10.0	19.4	14.9	23.5	23.0	29.6	38
1.0	20.4	7.1	22.5	9.3	25.9	13.1	29.9	18.3	36.3	27.9				
2.0 #	36.2	12.7	41.4	17.3#										
2.0	36.2	12.7	41.2	17.2										
3.0	51.7	18.2												

= results from non-simplified formulas

Table 6: Inductance of 4.8mm coil v number of turns v Standard Wire Gauge for close-wound single layer air-cored coil, of enamelled copper wire (based on G3BIK simplified formula).

Winding a coil with constant tension on the wire can be tiring to the fingers. It is a good ploy to have available a few pieces of self-adhesive tape to hold the turns in place during rest periods, or when mechanically anchoring the ends.

An inductor is only as good as its construction. If there is any slack in the finished product, a smear of epoxy-resin glue or nail varnish should hold the turns secure.

The easiest and least damaging method of straightening out enamelled copper-wire before commencing the winding, is to pull it gently through a cloth whilst nipping the wire between finger and thumb. Care must be taken when approaching loops in the wire to avoid kinking, which mechanically weakens the wire and damages the enamel insulation.

Older wire salvaged from electrical motors etc may have enamel that needs to be removed *carefully* prior to soldering, but the modern polyurethane enamels are said to be self-fluxing so do not need to be removed. The heat of the soldering-iron should in effect melt away the enamel coating without detriment to the quality of soldering. It is still wise to use a flux-cored solder rather than rely upon the polyurethane enamel as the fluxing agent. NOTE: It is wise to minimise the inhalation of fumes given off from the polyurethane coated wire.

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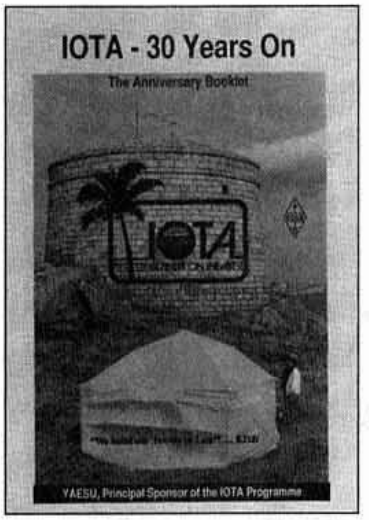

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